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MiniBooNE, Quo Vadis?

- Context
  - ν oscillation landscape
  - LSND
    - Implications
    - What if the signal is confirmed?
- Latest MiniBooNE news
  - Beam and Booster performance
  - Detector performance
    - calibration sources
    - optical modeling of the oil
    - detected neutrino rate
  - Neutrino data
    - flux, cross section progress
- Updated Oscillation Sensitivity based on first year of data (from Fall 2003 PAC)

New physics?

Getting better all the time

Rock steady

Many answers for many questions

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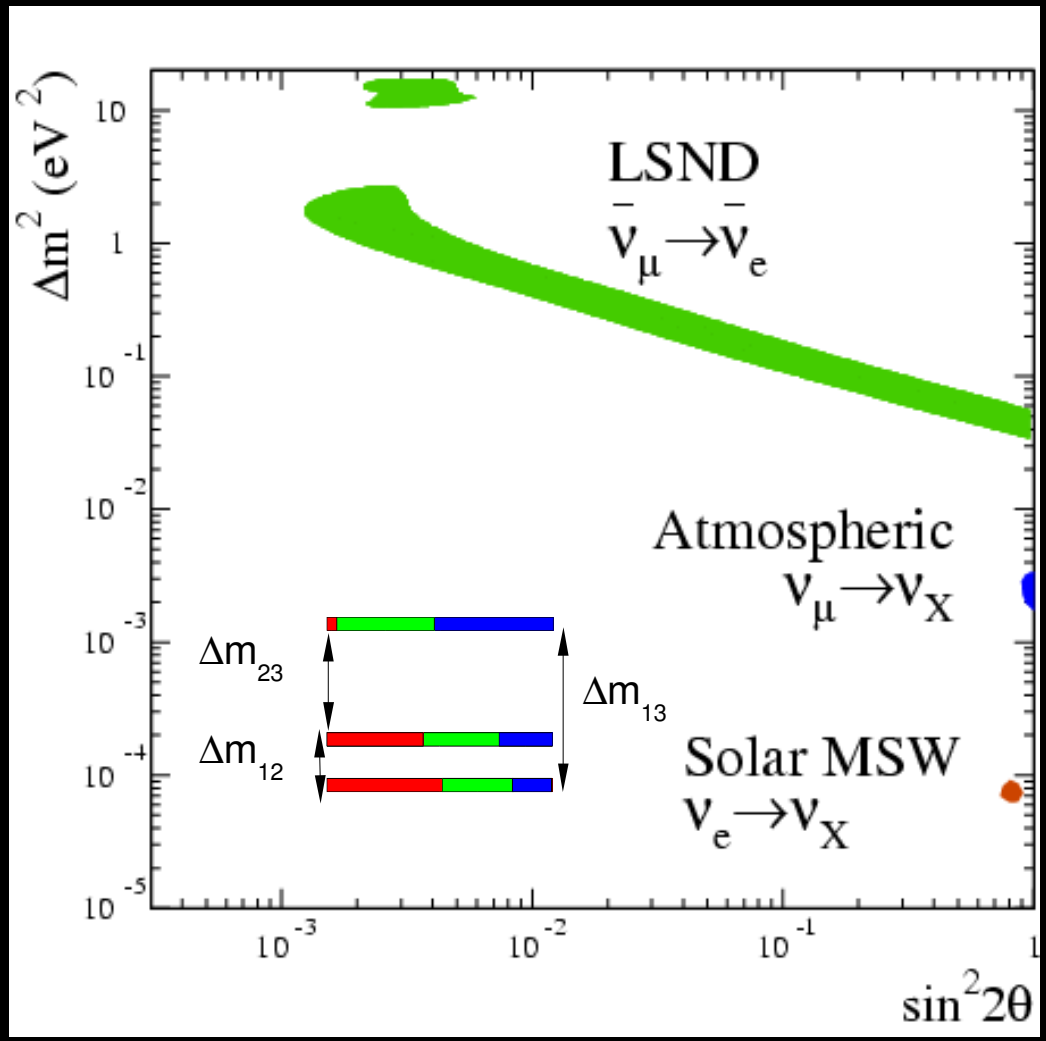
Motivation: 3 Δm^2 regions

- The 3 oscillation regions are incompatible with 3 standard model neutrinos
  - $10^{-5}+10^{-3} \neq 1$ (Solar+Atmospheric $\neq$ LSND)
  - Solar neutrino oscillations
    - Homestake
    - SNO
    - KamLAND
  - Atmospheric oscillation
    - first hints by Kamiokande
    - confirmed by Super-K
    - also seen by SOUDAN2, MACRO
  - LSND
    - Yet unconfirmed



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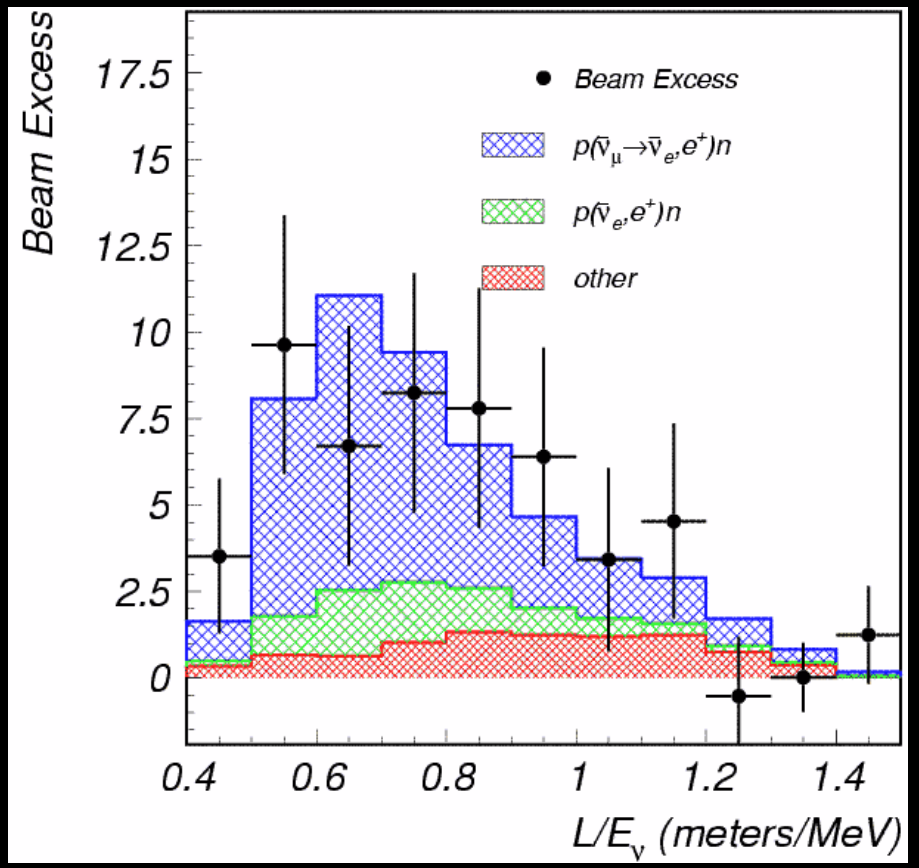
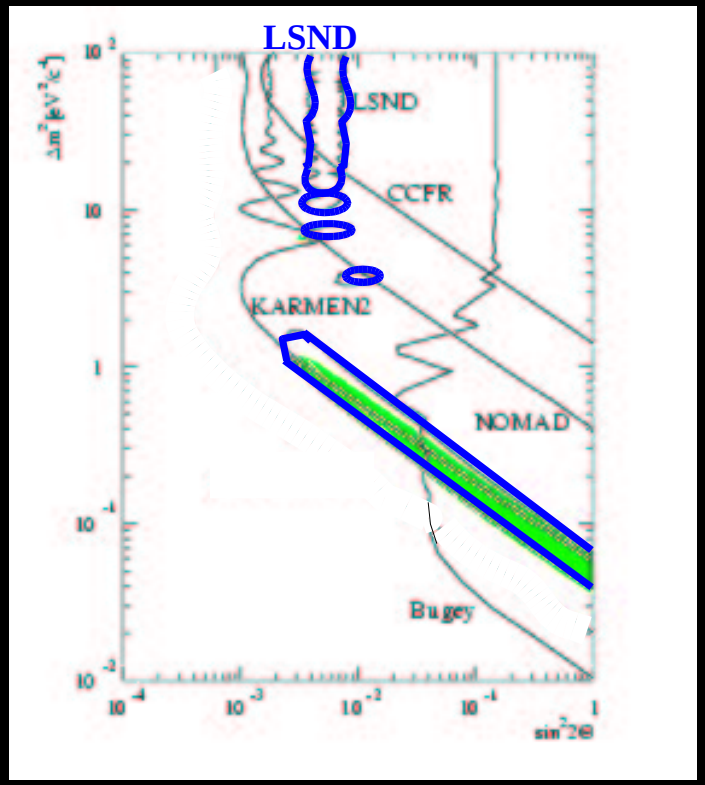
The LSND signal

- $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation probability:
  0.264±0.067±0.045%
- KARMEN2 and LSND collaborators performed joint analysis on both data sets - allowed regions remain!

4σ excess!



hep-ex 0104049



hep-ex/0203023

- High statistical significance - not easily ruled out

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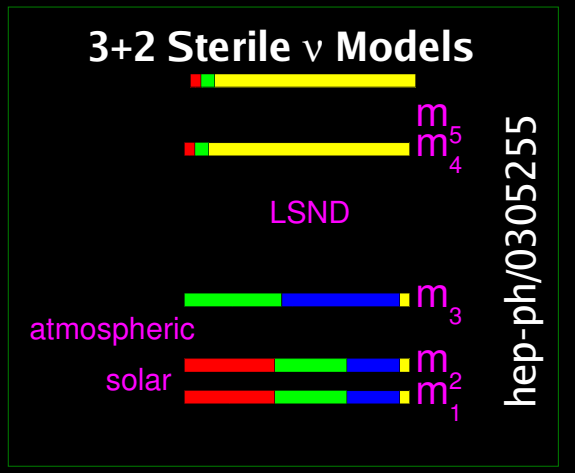
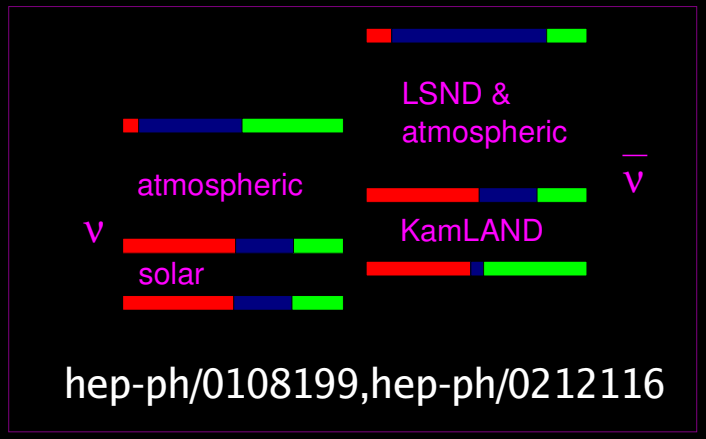
Interpreting LSND

- Not oscillations?
  - Anomalous muon decay: Ruled out by KARMEN2 at 90%CL (hep-ex/0302017)
- If it is oscillations, it indicates
  new physics beyond the standard model
- Sterile Neutrinos
  - (No weak coupling ⇐ invis. Z width)
  - 2+2 models all but ruled out
  - 3+1 models disfavored
  - 3+n models wide open (n>1)
- CPT Violation
  - ν, $\bar{\nu}$ mix separately
- Mass varying neutrinos (astro-ph/0309800)
- Many others
- MiniBooNE can confirm or exclude LSND w/ 1E21 POT

Neutrino key: ν_e ν_μ ν_τ ν_s





The LSND Signal has inspired fresh, new ideas.

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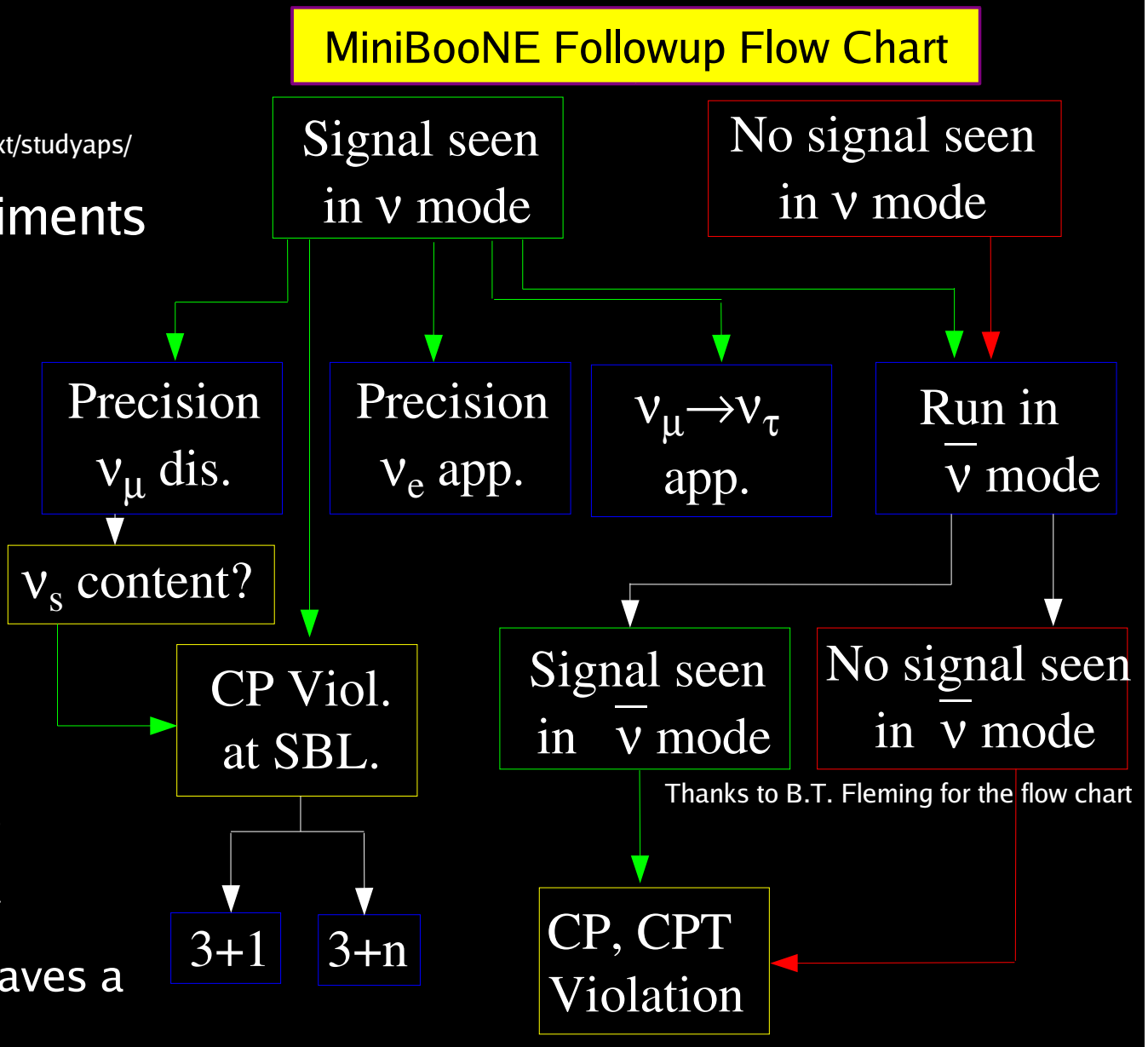
If LSND is Confirmed...

- APS Neutrino Study
  - Charge:
    http://www.hep.anl.gov/NDK/hypertext/studyaps/
- Many new SBL experiments proposed:
  - FINeSSE
  - MINERvA
  - T2K Near
- LSND oscillations important for future SBL
- LSND signal might be background for NOνA
  - Failure to exclude it leaves a large systematic error!
    (M. Shaevitz)



Thanks to B.T. Fleming for the flow chart

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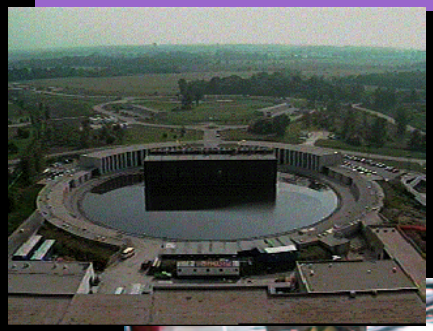
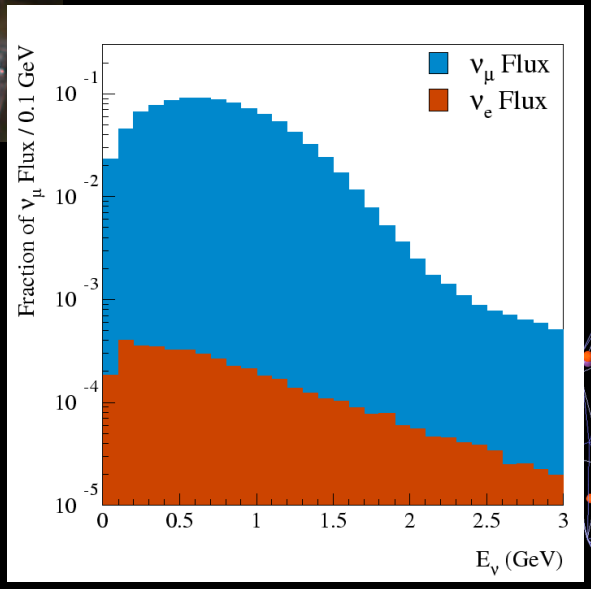
MiniBooNE Overview

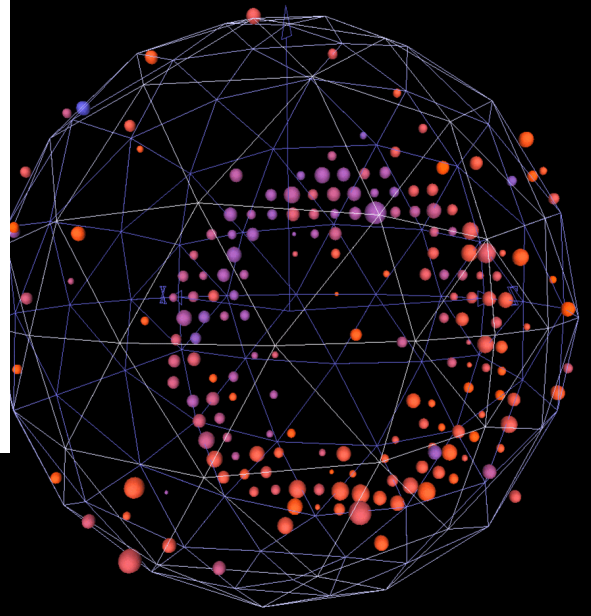


- 8 GeV protons from Booster
- Beryllium target

- Magnetic Horn to focus mesons
  - Over 76M pulses - a world record!
  - Reversible polarity - $\bar{\nu}$ mode



- 50m decay region
  - >99% pure ν_μ beam
- ~500m dirt
  - $\nu_\mu \rightarrow \nu_e$?
- 800 ton mineral oil detector
  - 1520 PMTs (1280+240 veto)



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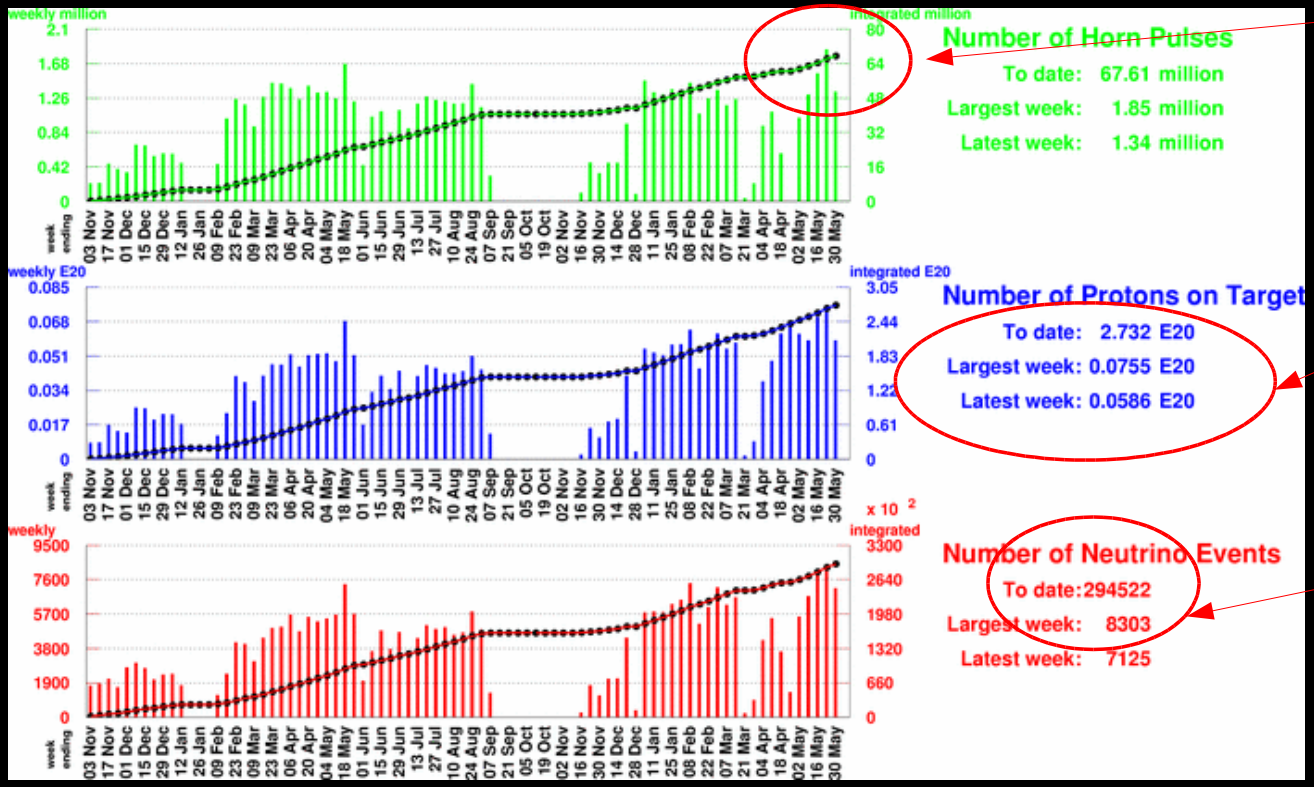
Beam Performance

- MiniBooNE Design request:
  - 5Hz × 5E12ppp × 88% ≈ 8E16p/hr → 0.13E20 p/week
  - getting closer all the time: recently at 60%!



http://www-boone.fnal.gov/publicpages/progress_monitor.html

Recent upturn in this slope bodes well!

Setting new records

Already the largest data set at these energies - ever!

Many thanks to Accelerator Division for getting us here!

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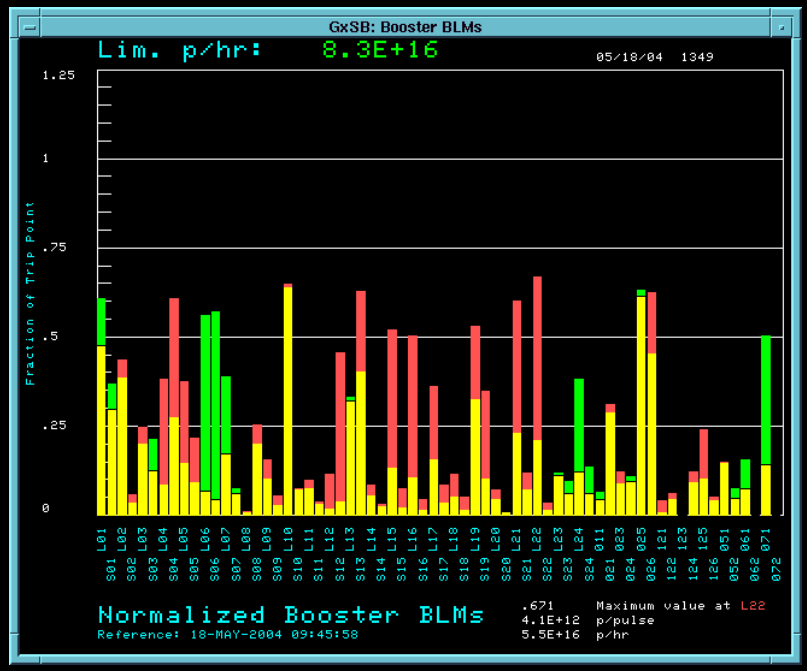
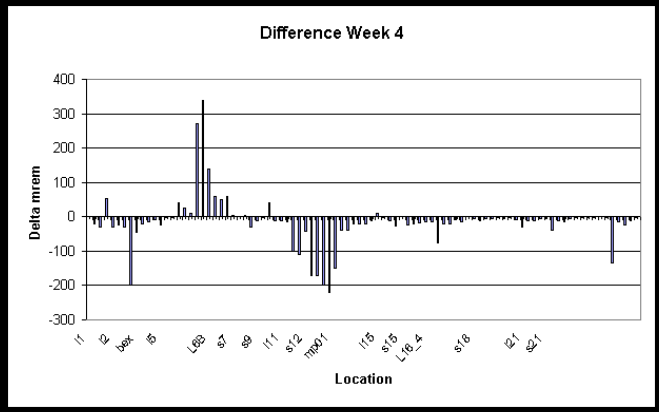
Booster performance

- Many factors contribute to improvements in the Booster
- Collimators
  - Commissioning nearly complete
    - standard configuration
  - Thank you Rapid Response Team
- Losses
  - Losses lower throughout Booster (except at collimators)
  - Activation already improving!
- Tuning, etc.
  - Thank you to the operators!
- MiniBooNE has made a big investment in the Booster





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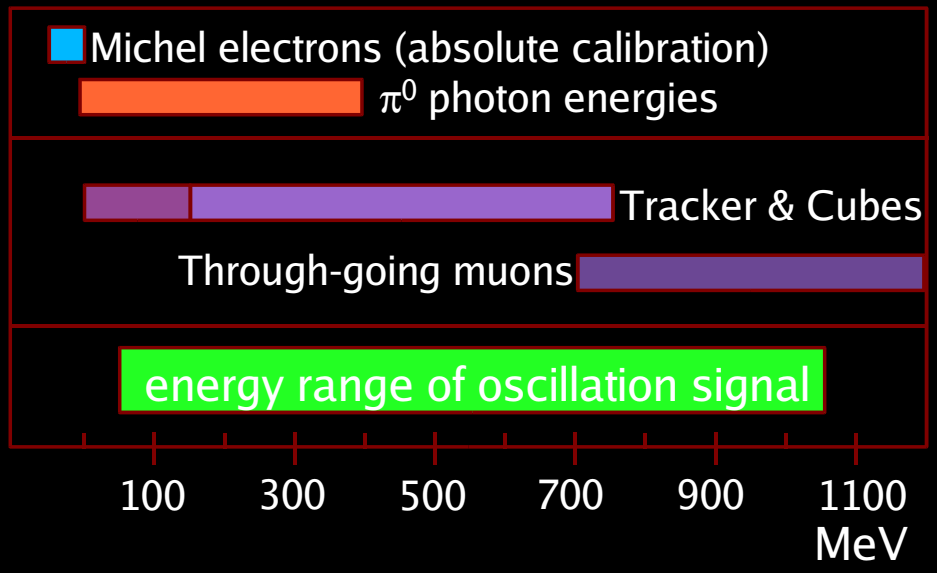
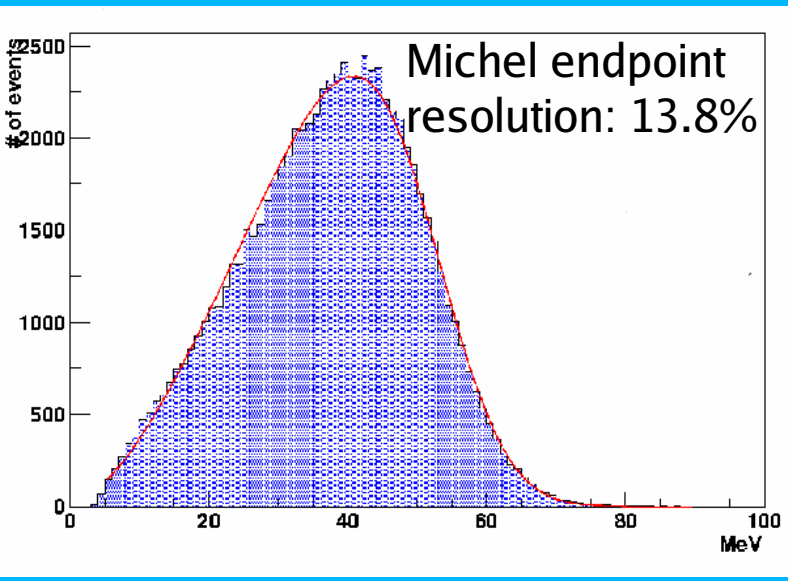
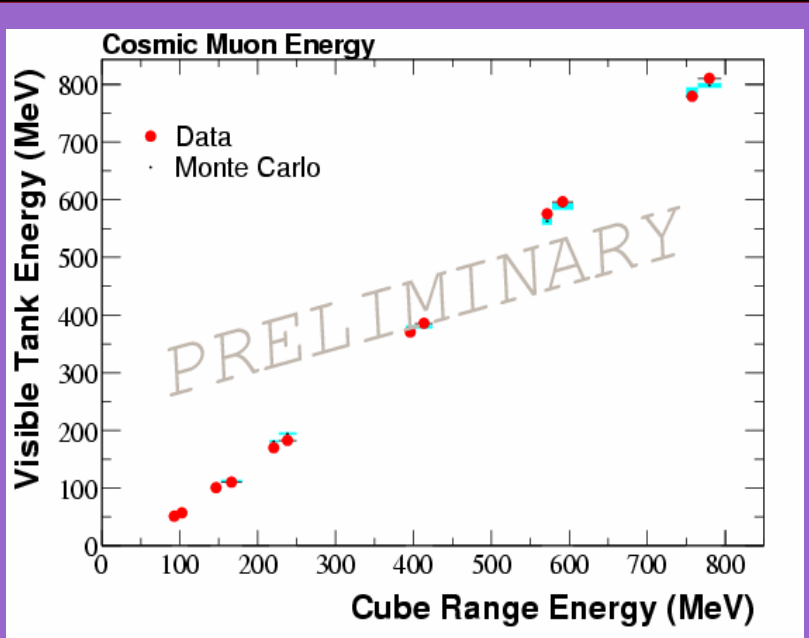
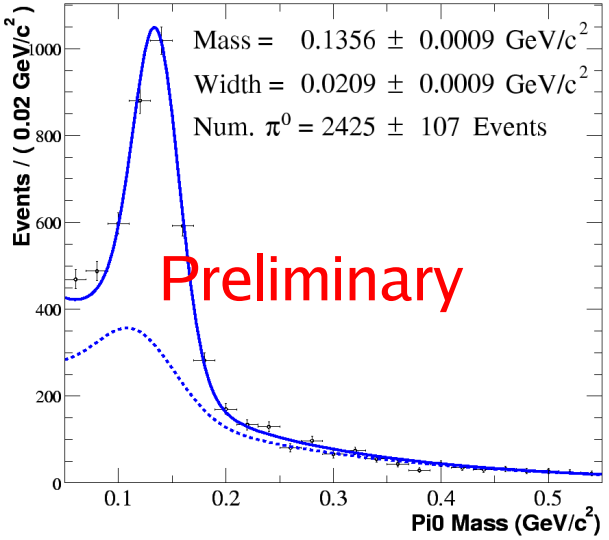
Detector Calibration









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Optics of Mineral Oil

Creation

- Čerenkov light
  - Proportional to β
- Scintillation
  - dE/dx

Propagation

- Scattering (Rayleigh)
  - prompt
  - $1+\cos^2\theta$
  - λ^4
- Fluorescence
  - isotropic
  - time delayed
  - spectrum
- Absorption

In Situ

- Michel electrons
- Cosmic Muons
- Laser: diffuse light
- Laser: pencil beam

Ex Situ

- Scintillation (IUCF) w/p^+
- Scintillation (FNAL) w/μ
  - Repeated w/p^+ (IUCF)
- Goniometry (Princeton)
- Fluorescence spectroscopy (FNAL)
- Time resolved spectroscopy (JHU)
- Attenuation (FNAL)
  - several devices

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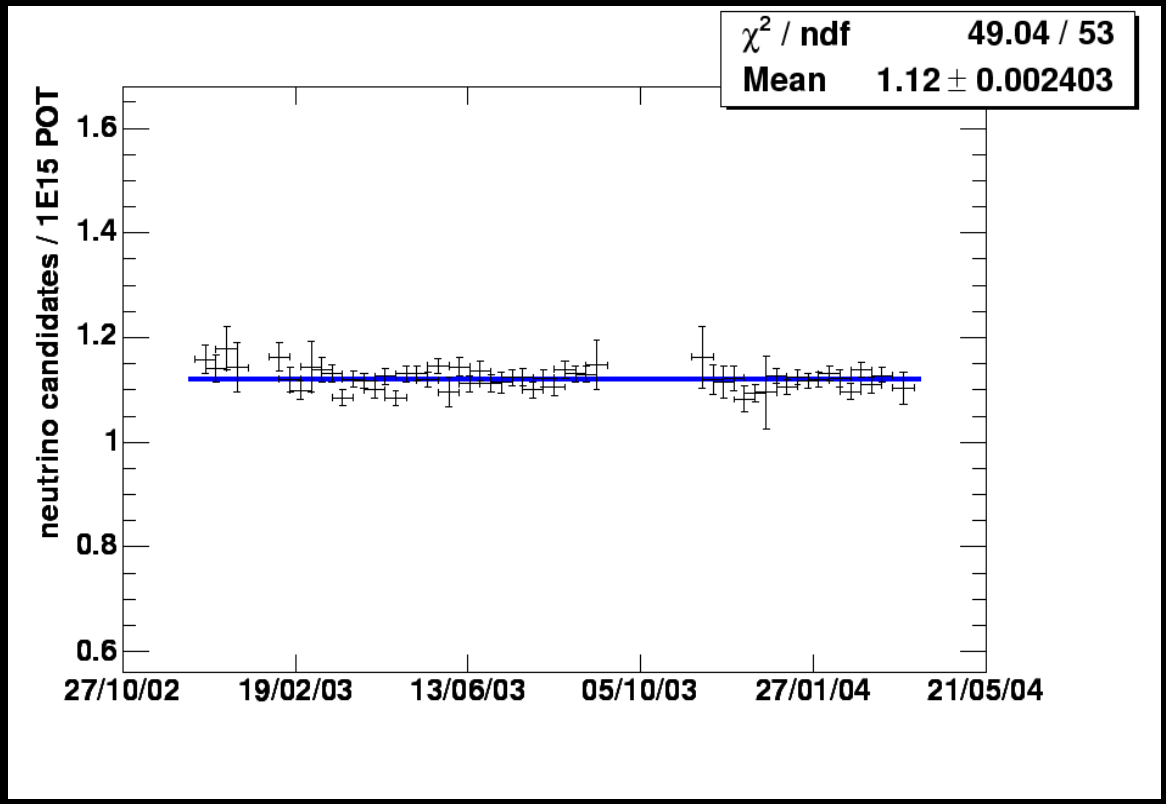
Neutrino Detection

- Measured rate of neutrinos candidates
  - per 1E15 P.O.T
  - Neutrino candidates≡
    - >200 tank hits
    - <6 veto hits
- Constant over time
- Tests performance of:
  - Tank DAQ
  - ACNET DAQ
  - Calibration stability
  - Data processing chain



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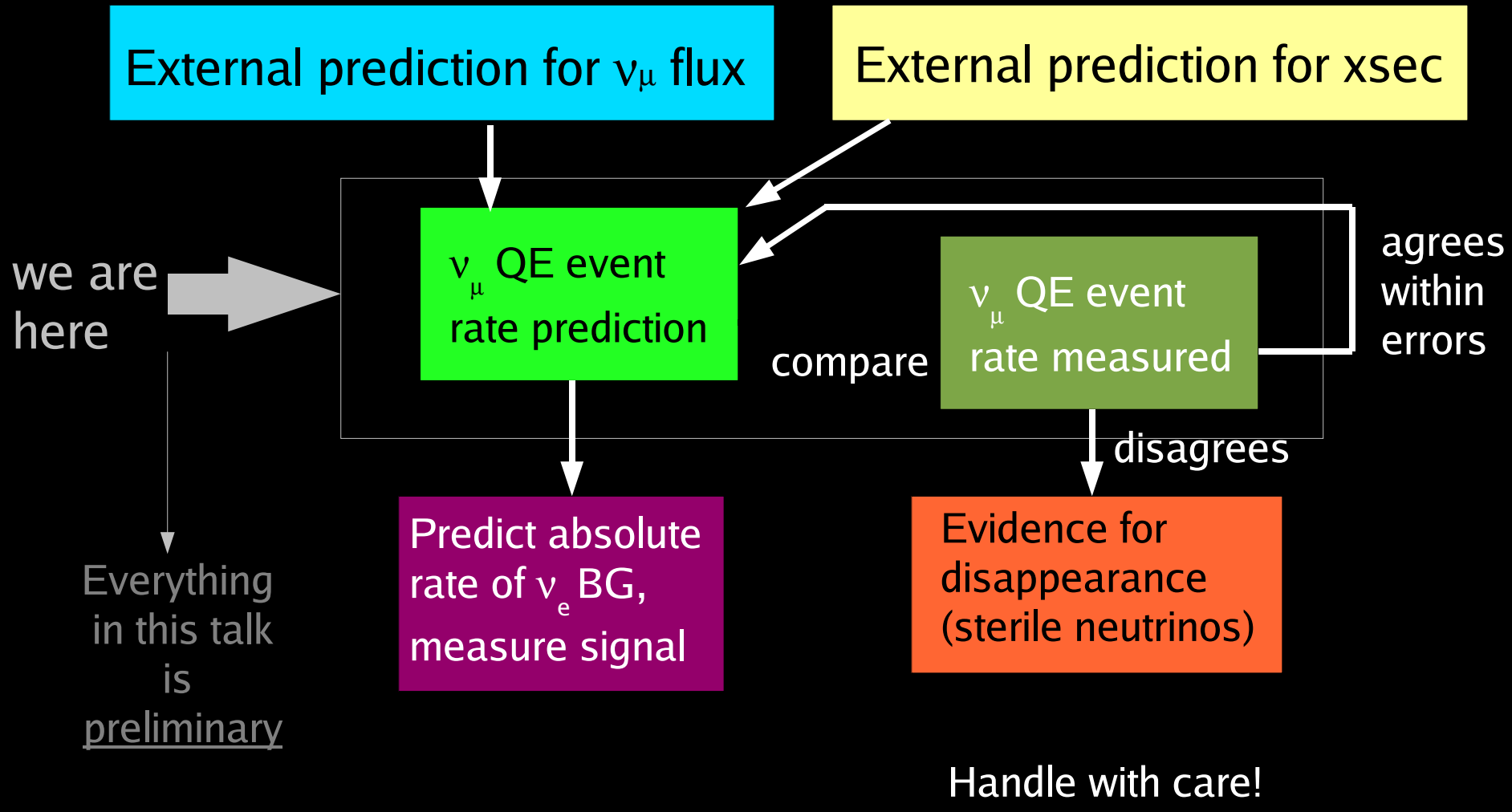
Road to Results 1



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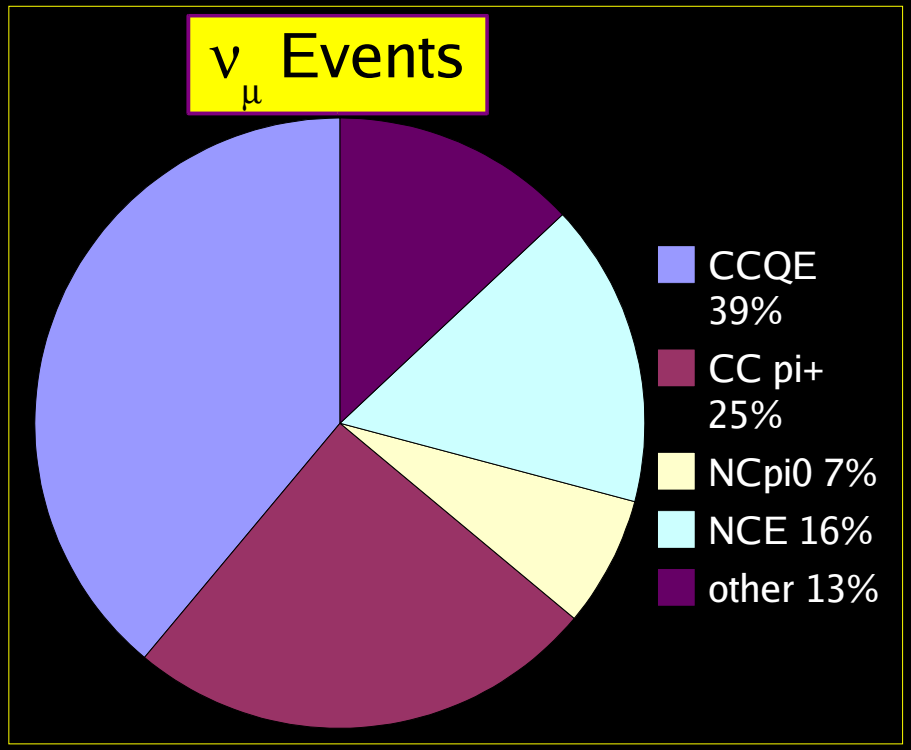
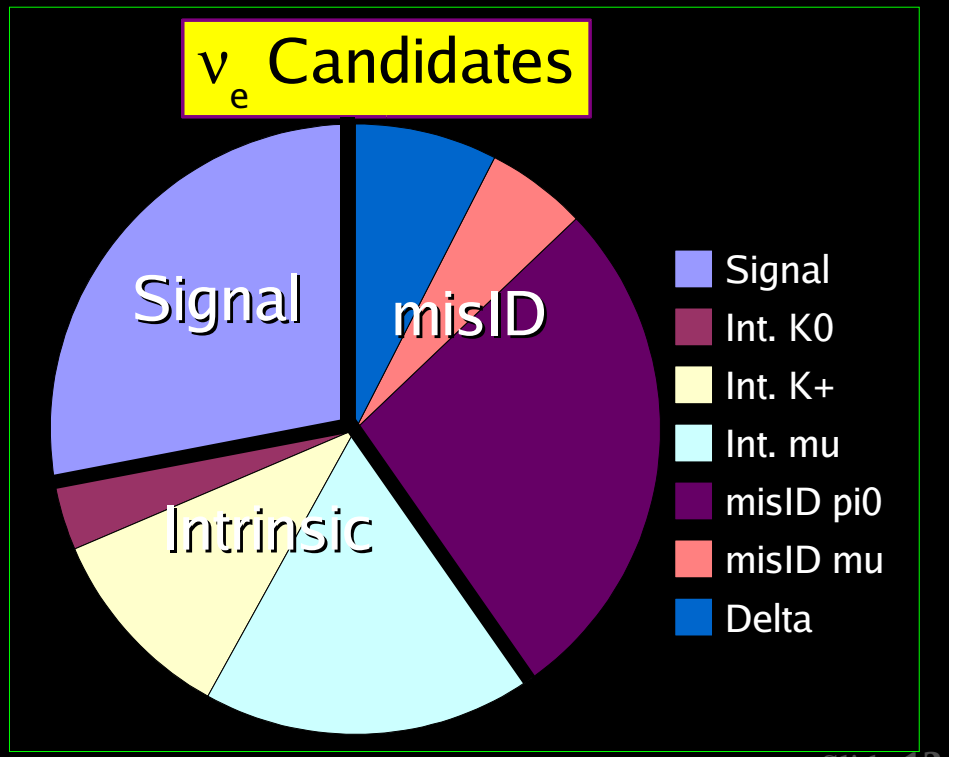
Road to Results 2



- >99% of events are ν_μ:
  - 39% CC quasi elastic
  - 25% CC π^+
  - 7% NC π^0
  - 16% NC elastic
  - 13% other



- Expect to see ~1080 ν_e QE
  - 300 oscillation signal events
  - 350 Intrinsic ν_e in beam
    - K^+, K^0, μ decay
  - 430 misID events
    - μ, π^0, Δ

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Big, bad

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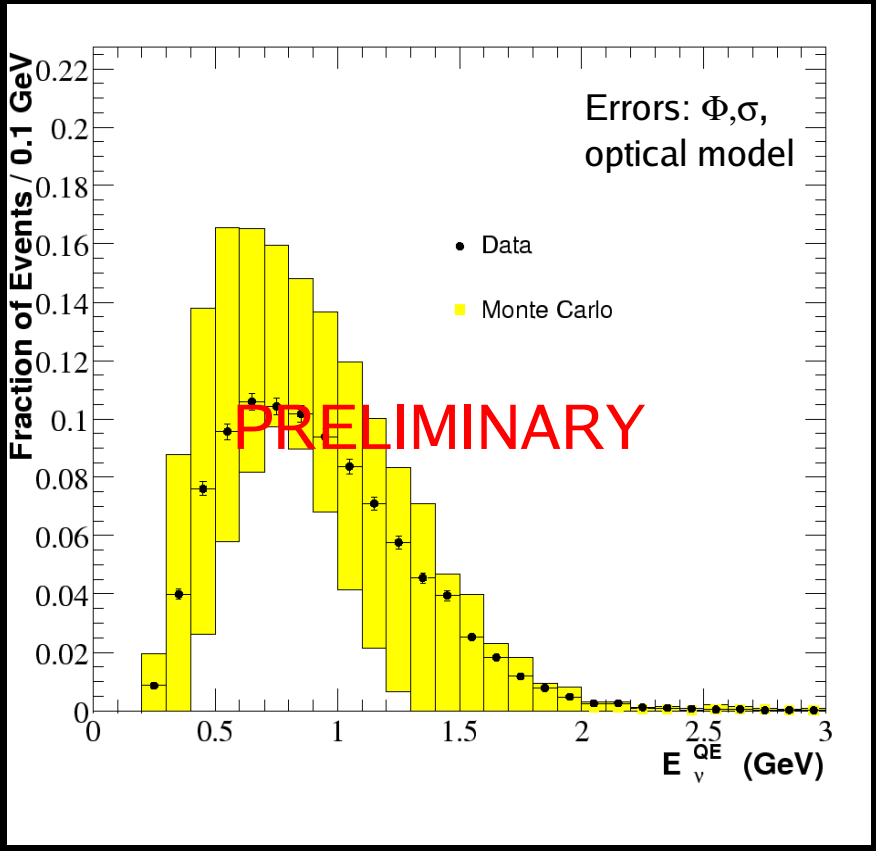
Understanding the flux

- External pion production measurements
  - E910
    - Beryllium target
    - 6.4GeV/c, 12.3GeV/c, 17.5 GeV/c
  - HARP
    - MiniBooNE target slugs
      - 5%, 50%, 100% λ
    - 8GeV protons
- Fit pion data with Sanford-Wang model
- Calculate neutrino flux at detector, and compare to data

$$E_\nu^{QE} = \frac{1}{2}\,\frac{2\,M_p E_\mu - m_\mu^2}{M_p - E_\mu + \sqrt{(E_\mu^2 - m_\mu^2)}\,\cos\theta_\mu}$$



- Measure:
  - muon energy: ±10%
  - muon direction ±45mrad
- Neutrino energy res.: 10-15%

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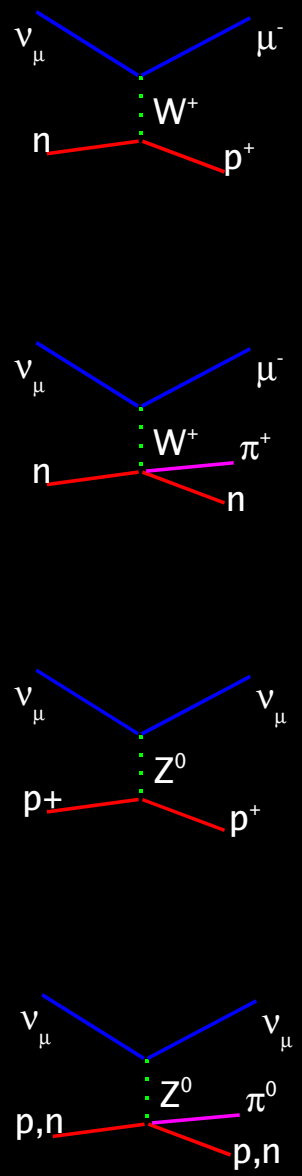
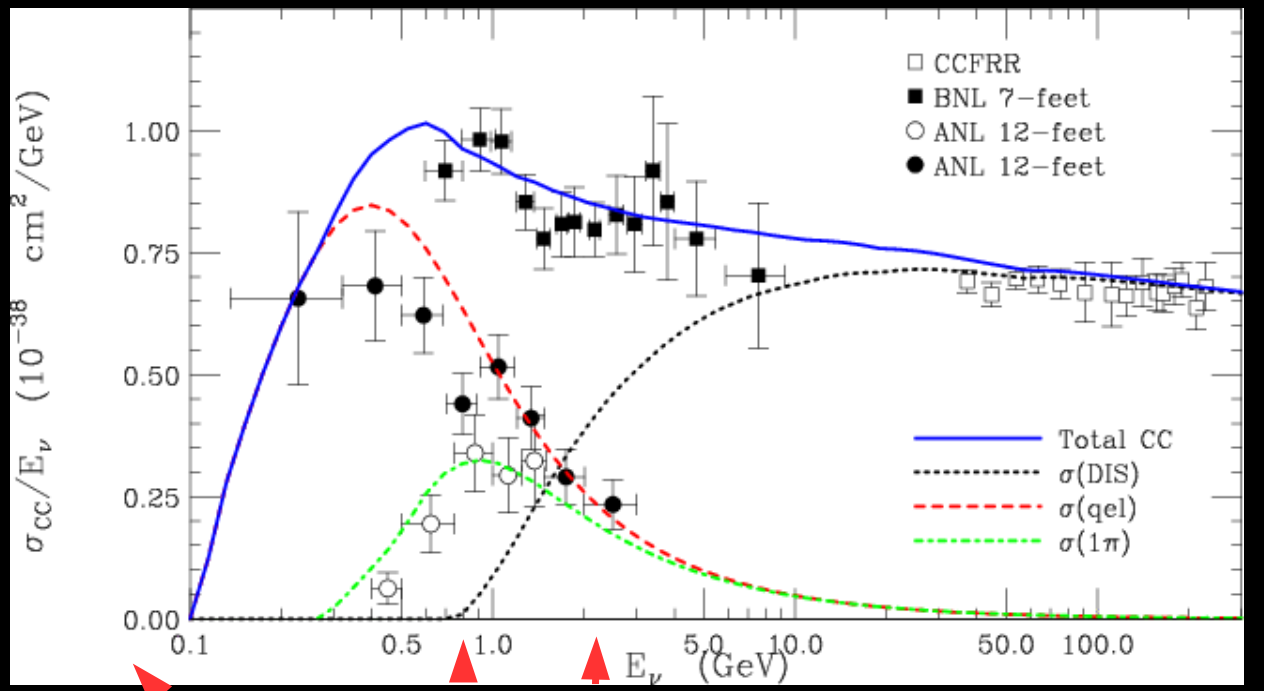
Understanding Cross Sections 1

- >290,000 neutrino events and counting!
  - 113k CCQE
  - 72k CC $1\pi^{\pm}$
  - 46k NC E
  - 20k NC π^0



P. Lipari, Nucl. Phys. Proc. Suppl. 112, 274 (2002) (NuInt01)



LSND

MiniBooNE

K2K

Super-K atmospheric νs

Range of NuMI Possibilities

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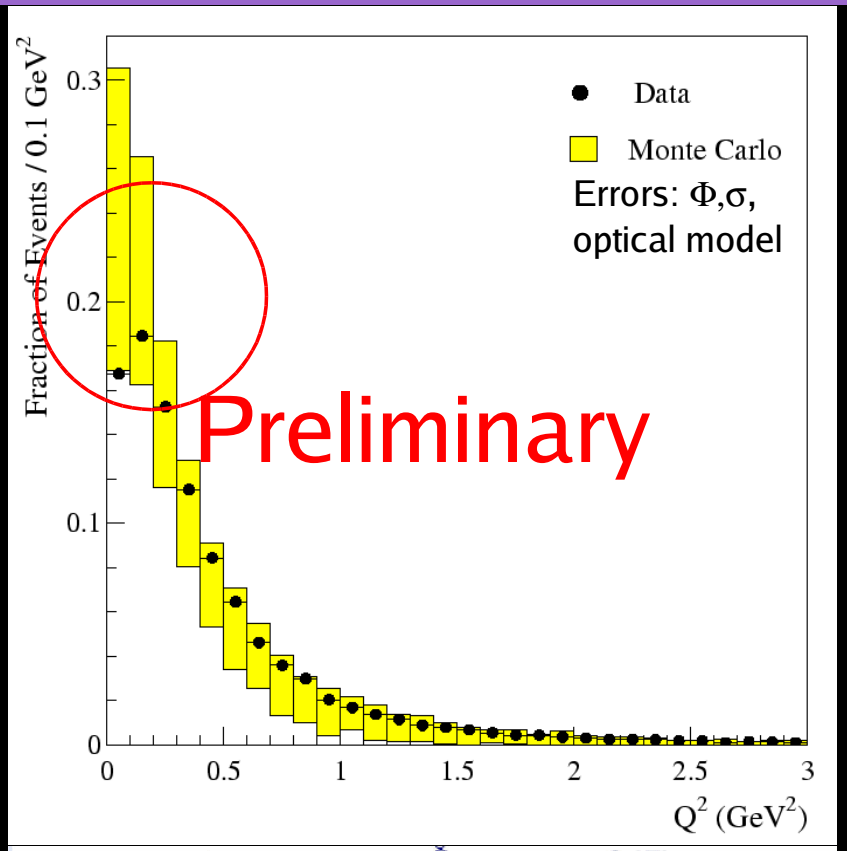
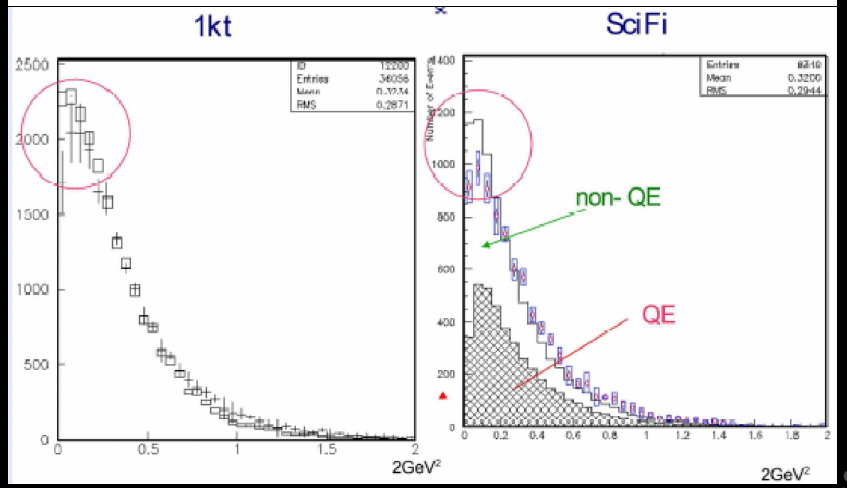
Cross Sections 2

- Nuclear effects important at MiniBooNE neutrino energies
  - Pauli blocking and simple nuclear effects included in NUANCE MC
  - Reduction in low Q^2 rate previously observed by BEBC comparing Ne to D data sets
    P. Allport et al., Phys. Lett. B232, 417 (1989)
- Observed reduction exceeds Pauli blocking prediction
  - Nuclear shadowing?
  - Also observed by K2K near detectors
  - Generated much interest at NuInt04 in March





need reference

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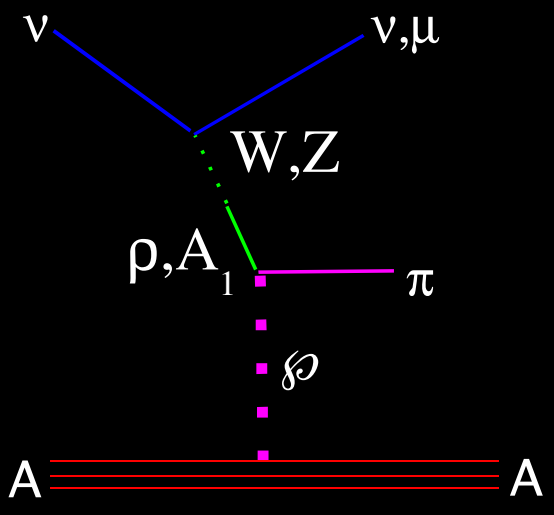
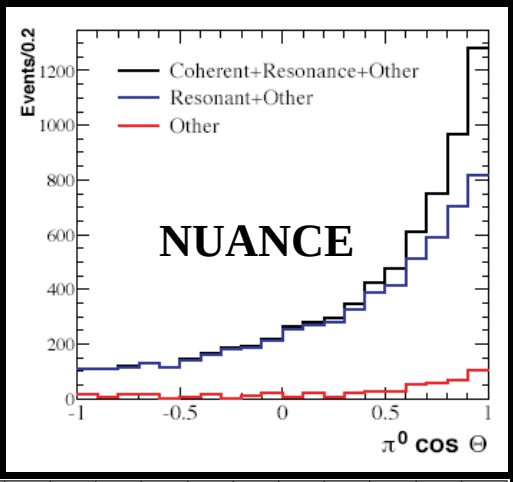
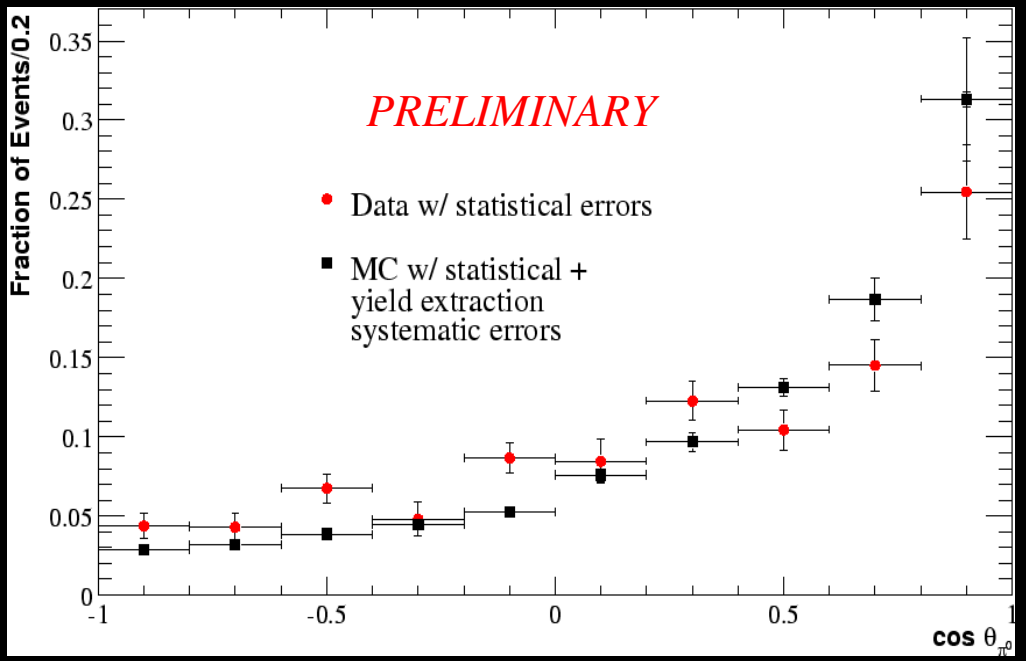
Cross Sections 3

- Neutral Current π^0 production: coherent/resonant ratio?
- Coherent: ν scatters w/ whole nucleus
  - diffractive scattering (Pomeron)
  - Clear signature: forward-peaked
  - ~20% of $\sigma(\nu_\mu N \rightarrow X\pi^0)$ at 1 GeV
  - competing models differ by 20X!
- No data published below 2 GeV







- Super-K BG for $\nu_\mu \rightarrow \nu_s$ vs. $\nu_\mu \rightarrow \nu_\tau$

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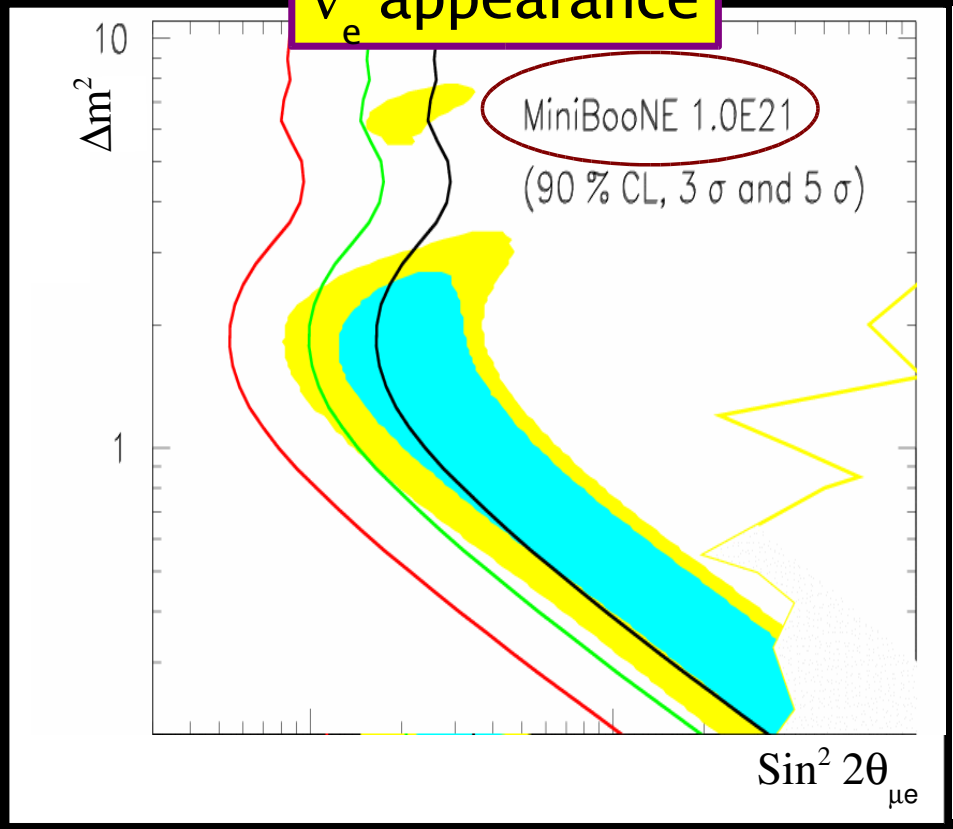
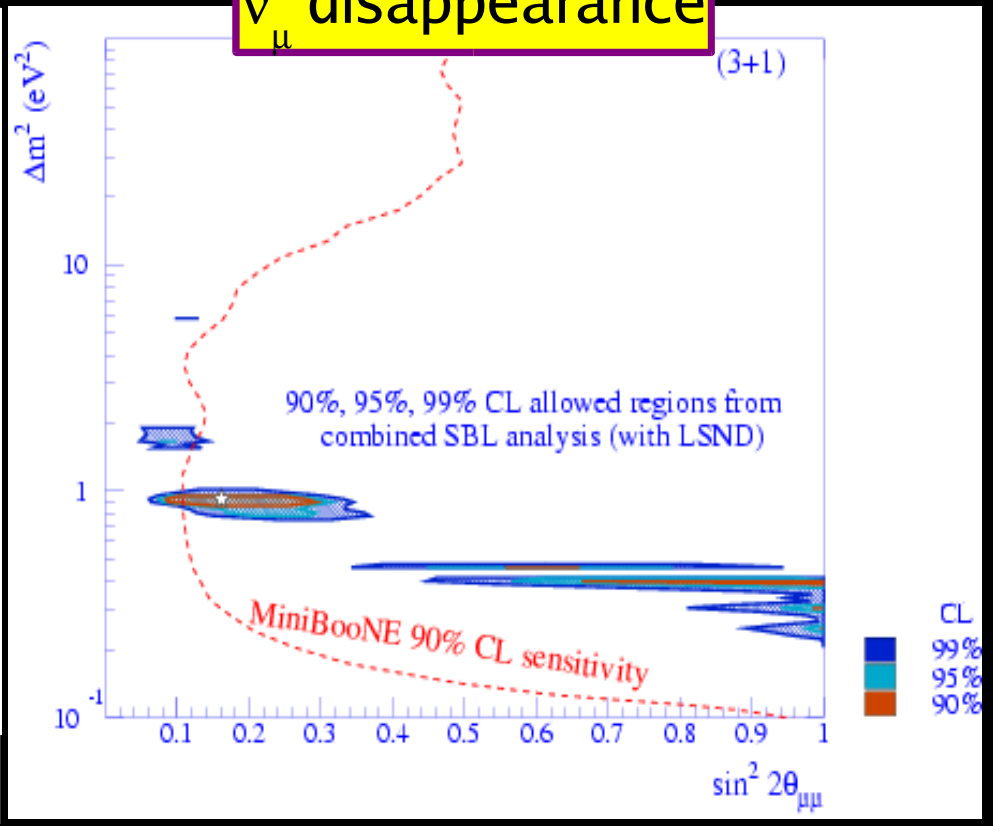
Oscillation Sensitivity

- Updated sensitivity based on first year of data (Fall 2003 PAC)

ν_e appearance



ν_μ disappearance



www-boone.fnal.gov/publicpages/news.html

Many thanks to JR.Monroe and M.Sorel for the plot

- Can exclude LSND allowed region at high statistical level only with 1E21 POT

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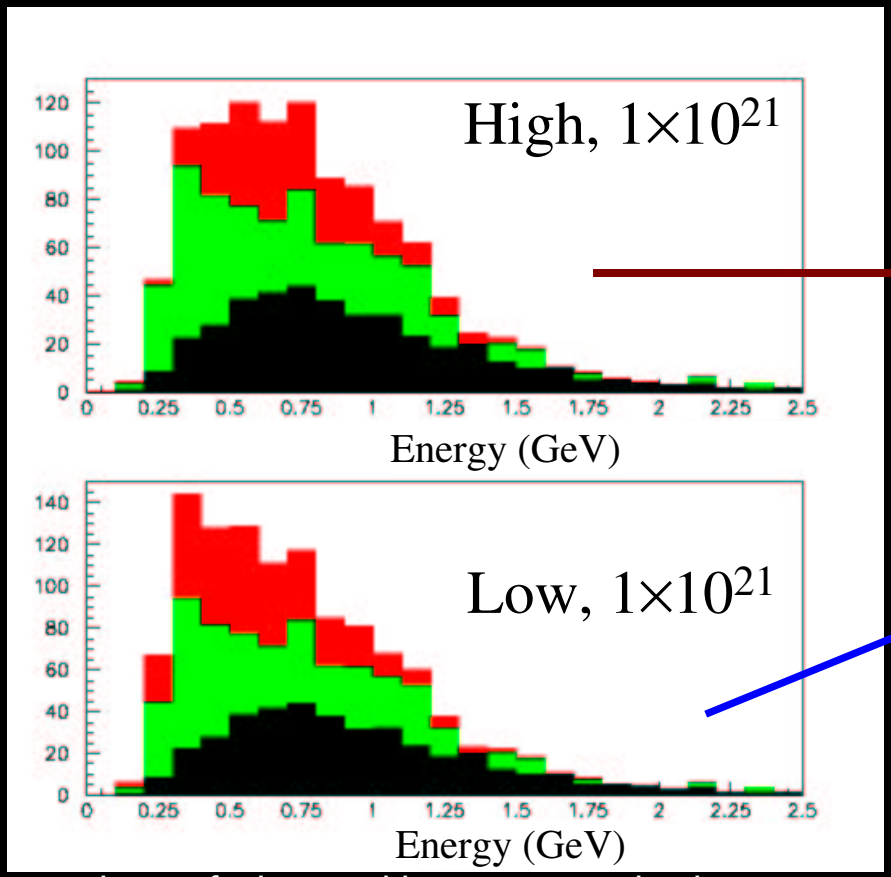
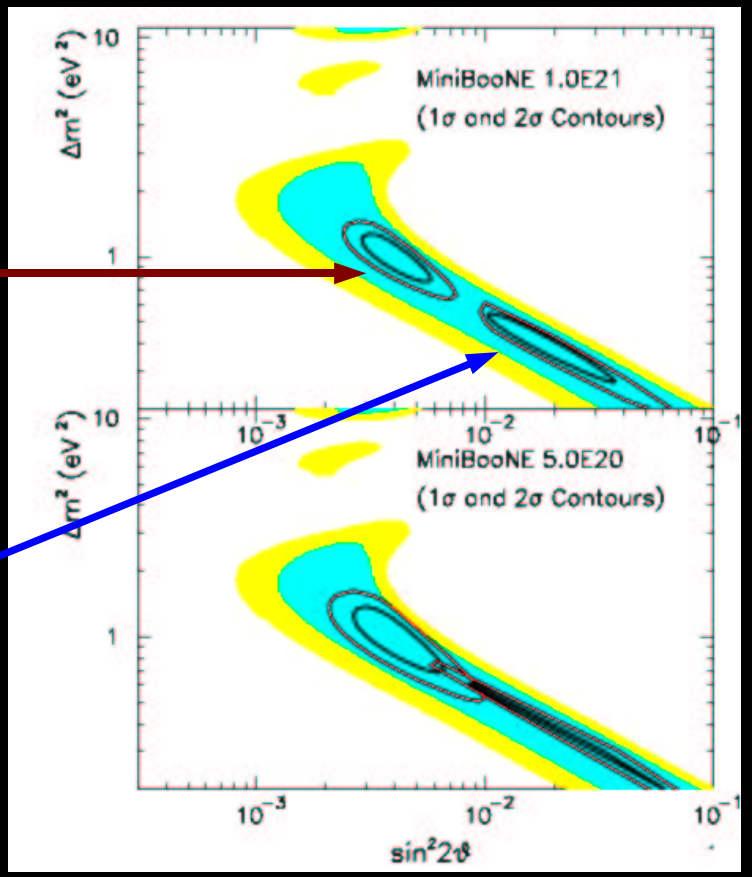
Measuring Δm^2





www-boone.fnal.gov/publicpages/news.html

- Can differentiate high and low Δm^2 regions with 1E21 POT
- High vs. low Δm^2 is important for near future experiments

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Conclusions

- MiniBooNE data coming in fast
- Booster improvements continue
  - Collimators will provide at least 30% more improvement
- HARP results will finalize flux predictions
  - Pion and Kaon rate
- LMC will measure K^+ rate
- high statistics will allow important low energy cross section measurements
- Optical model being pursued vigorously
  - Parameters should be set this fall
  - Final error matrix as well
- Tank energy calibrations indicate good reconstruction, resolution
- Analysis work proceeding well
- Will be fully ready to open box when 1E21 POT are collected